



# Impact of pest management practices on the frequency of insecticide resistance alleles in *Bemisia tabaci* (Hemiptera: Aleyrodidae) populations in three countries of West Africa

Olivier Gnankine, Omer Hema, Moussa Namountougou, Laurence Mouton, Fabrice Vavre

## ► To cite this version:

Olivier Gnankine, Omer Hema, Moussa Namountougou, Laurence Mouton, Fabrice Vavre. Impact of pest management practices on the frequency of insecticide resistance alleles in *Bemisia tabaci* (Hemiptera: Aleyrodidae) populations in three countries of West Africa. *Crop Protection*, 2018, 104, pp.86 - 91. 10.1016/j.cropro.2017.10.020 . hal-01916784

**HAL Id: hal-01916784**

**<https://hal.science/hal-01916784>**

Submitted on 10 Jan 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**Impact of pest management practices on the frequency of insecticide resistance alleles in *Bemisia tabaci* (Hemiptera: Aleyrodidae) populations in three countries of West Africa.**

**Olivier Gnankiné<sup>a</sup>, Hema Omer<sup>b</sup>, Moussa Namountougou<sup>c</sup>, Laurence Mouton<sup>d</sup> and Fabrice Vavre<sup>d</sup>**

<sup>a</sup> Laboratoire d'Entomologie Appliquée, **Université de Ouaga I Pr Joseph KI-ZERBO**, Burkina Faso.

<sup>b</sup> Institut de l'Environnement et de Recherches Agricoles, BP 390 Bobo-Dioulasso, Burkina Faso

<sup>c</sup> Université Nazi Boni de Bobo-Dioulasso, Burkina Faso

<sup>d</sup> Université de Lyon, Université Lyon 1, CNRS, Laboratoire de Biométrie et Biologie Evolutive UMR5558, F-69622 Villeurbanne, France.

\* Corresponding author: Laboratoire d'Entomologie Fondamentale et Appliquée, Département de Biologie et Physiologie Animales, Université de Ouagadougou, 03 BP 7021 Ouagadougou 03, Email : [olivier.gnankine@univ-ouaga.bf](mailto:olivier.gnankine@univ-ouaga.bf); [olgnankine@hotmail.com](mailto:olgnankine@hotmail.com)

## ABSTRACT

In West Africa, the use of organophosphates and pyrethroids insecticides to control cotton pests has led to the evolution of resistance in field populations of *Bemisia tabaci* Gennadius. Three pest management programs have been commonly recommended: the Conventional Program (CP) where 6 treatments are applied, the use of *Bt* cotton plants for which only 2 applications of neonicotinoids are required and that has been adopted in many countries, and a biological program (BP) without any chemical treatment. The present study aims to determine the influence of these practices on the frequency of mutations that confer resistance to pyrethroids (mutation L925I in the *para*-type voltage-gated sodium channel gene) and organophosphates (mutation F331W in the acetylcholinesterase enzyme *ace1*: allele *Ace1<sup>R</sup>*) in *B. tabaci* populations using *Bt* cotton and CP areas in Pô and Saria (Burkina Faso), CP and BP areas in Kandi (Benin) and only CP areas in Tové and Infa (Togo). All individuals sampled belonged to the MED (biotypes MED-Q1) and Africa Silver Leafing (ASL) species. MED-Q1 was found in sympatry with ASL in Burkina Faso both on CP and *Bt* cotton areas at variable frequencies. In Togo and Benin, only ASL was found, except in Tové where MED-Q1 was also detected, but at low frequency. Frequencies of mutations that confer resistance varied between localities and species but we did not find any strong evidence of a relationship between the pest management program and these frequencies except for the allele *Ace1<sup>R</sup>* in Burkina Faso for which the frequencies decrease when chemical applications are reduced. This study provides valuable information for the development of efficient integrated pest management programs.

**Key words:** Pest management programs, insecticides, *kdr*, *Ace1<sup>R</sup>*, *Bemisia tabaci*.

## 1. Introduction

In western Africa, cotton is an economically important crop providing substantial incomes for farmers. However, the cotton plant is attacked by key pests including the cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae) and the whitefly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae). Three main spraying programs are recommended to control these pests in many countries of West Africa. They include the Conventional Cotton program (CP), the Biological Program (BP) and the transgenic *Bt* cotton program (*Bt* Cotton). The CP is based on calendar-based applications of insecticides belonging to pyrethroids, organophosphates and neonicotinoids families separately or as a mixture (Gnankiné et al., 2013a; Silvie et al., 2013). They are applied with temporal rotations during the whole cotton season (from May to October). The repeated use of such insecticides have imposed strong selection pressures on target pests' populations, resulting in the evolution of field resistances (Houndeté et al., 2010). Over \$60 millions of chemicals were spent for chemical pests control in Burkina Faso (Greenplate et al., 2006). The BP relies on the use of biopesticides and natural fertilizers without utilization of any chemical. The *Bt* cotton program uses *Bt* (*Bacillus thuringiensis*) transgenic cotton plants that express two crystal toxins (Cry1Ac and Cry2Ab) that target some major lepidopteran pests but are harmless to vertebrates and most other organisms (Mendelsohn et al., 2003; Sanahuja et al., 2011; Pardo-Lopez et al., 2013). In this program, only neonicotinoids are used at the end of the cotton phenological stages (Héma et al., 2009). It was initiated in 2008 in West Africa but only in Burkina Faso. In 2016, the Burkina Faso government suspended the use of *Bt* technology due to the quality of cotton fiber which is shorter than the fiber of conventional cotton.

One of major threat to cotton plant remains the whitefly *B. tabaci*. It causes damages directly through phloem feeding and indirectly through the transmission of plant viruses. *B. tabaci* is a

complex of cryptic species whose taxonomy is still not entirely resolved. Based on the current consensus, *B. tabaci* is mostly represented by the MED species in western Africa, even though AnSL species can also be found (Gnankiné et al., 2013b; Gnankiné et al., 2013c). Within the MED species, different biotypes are encountered including MED-Q1, MED-Q3 and ASL. Actually, recent analyses suggest that MED-Q1 and ASL do not hybridize in the field and that ASL is thus a different species (Mouton et al., 2015). Interestingly, these species/biotypes differ in terms of host plants range and insecticide resistance traits. Generally, MED-Q1 is predominant in cotton areas and sometimes found in sympatry with ASL on vegetables crops (Gnankiné et al., 2013b). It is also associated with higher levels of resistance to some insecticides as pyrethroids, organophosphates and neonicotinoids (Gnankiné et al., 2013a). In *B. tabaci*, two mutations in the *para*-type voltage-gated sodium channel gene, L925I and T929V, and one mutation in the acetylcholinesterase enzyme *ace1* (F331W: allele *Ace1<sup>R</sup>*) confer resistance to pyrethroids and organophosphates, respectively (Roditakis et al., 2006; Alon et al., 2008; Tsagkarakou et al., 2009). Recent studies showed that the *Ace1<sup>R</sup>* was found in both MED-Q1 and ASL but, while this resistant allele was almost fixed in MED-Q1 (0.99), its frequency was 0.59 in ASL (Mouton et al., 2015). In addition, while the L925I mutation in the sodium channel gene is almost fixed in MED-Q1 populations, it is rarely detected in ASL. The T929V was never found in *B. tabaci* populations from West Africa (Mouton et al., 2015). The objectives of the present study were to perform a first analysis of the impact of the agricultural practices on the *B. tabaci* biotypes/species composition and diversity, and the frequencies of alleles that confer resistance to pyrethroids and organophosphates. Sampling was performed in three countries of Western Africa: Burkina Faso, Benin and Togo.

112

## 113 2. Materials and methods

### 114 2.1 Management of cotton pests

115 Three pest control programs are recommended in West African countries:

116 (i) The Conventional Program (CP) is based on two to four treatments with pyrethroids (PY)  
117 plus organophosphates (OP) and 2 other treatments with neonicotinoids (see table 1 for  
118 details).

119 (ii) The Biological control Program (BP) does not use chemicals for plant protection. Farmers  
120 worked under the supervision of technicians from the Beninese Organization for Organic  
121 Farming Promotion (OBEPAP) who participated in the implementation and the survey of  
122 good agricultural practices on organic cotton.

123 (iii) The transgenic cotton program (*Bt* Cotton). In this program, pesticides belonging to OP  
124 and PYR are not used. Only neonicotinoids are used at boll opening stage to control sucking  
125 pests. In this case, farmers worked under the supervision of technicians from societies of  
126 textile fibers in Burkina Faso.

127

### 128 2.2 *B. tabaci* sampling

129 Sampling was performed in october and november between 2009 and 2015 in three countries  
130 of Western Africa: Burkina Faso, Benin and Togo (Figure 1, Table 2). In Burkina Faso,  
131 whiteflies were collected randomly in two localities, Pô in 2013 and Saria in 2015, from *Bt*  
132 cotton and CP fields. In Pô, *Bt* cotton represented 90% of the sampled fields while in Saria it  
133 represented 15%. In Benin, sampling was done at Kandi in 2009 in CP and BP areas (BP  
134 represent around 10% of areas). In Togo, collection was done randomly in two sites in 2009,  
135 Infa and Tové, where only CP is used. The collected adult whiteflies were stored in ethanol

95%. The origin of the samples (location) and the number of individuals are summarized in Table 2.

## 2.3 Molecular analysis

### DNA extraction

For each individual, total DNA was extracted in 25 µl of an extraction buffer containing 50 mM KCl, 10 mM Tris-base pH 8, 0.45% Nonidet P-40, 0.45% Tween 20 and 50 mg/ml proteinase K. After 3 h at 65°C, samples were incubated at 100°C for 15 min. Pure water (35 µl) was then added to the extract.

### Identification of *B. tabaci*

Species/biotypes were identified using the Polymerase Chain Reaction-Random Fragment Length Polymorphism (PCR-RFLP) diagnostic assay based on the mitochondrial cytochrome oxidase 1 gene sequence (*mtCOI*) described in Henri et al. (2013). This technique allows discriminating the species/biotypes present in West Africa (Gnankiné et al., 2013b).

### Identification of susceptible and resistant alleles of the sodium channel and the acetylcholinesterase *ace1* genes

Resistant and susceptible alleles in the *para*-type voltage-gated sodium channel and *ace1* genes were identified using the diagnostic assays developed by Tsagkarakou et al. (2009). Briefly, *ace1*-susceptible (F331) and -resistant (W331) alleles, as well as susceptible (L925) and resistant (I925) *para*-type voltage-gated sodium channel alleles were detected using PCR-RFLP (Tsagkarakou et al. 2009). Some PCR products were sequenced for each susceptible and resistant allele and each country. We never found the T929V mutation in the sequences.

The frequencies of *kdr* and *ace-1<sup>R</sup>* mutations were calculated according to the formula

$$p = \frac{n\sigma^{\nearrow}(R) + 2n\sigma^{\circ}(RR) + n\sigma^{\circ}(RS)}{n\sigma^{\nearrow} + 2n\sigma^{\circ}}$$
 where RR was the number of homozygotes, RS the number of heterozygotes and n the size of specimens analysed.

## 2.4 Statistical analyses

Statistical analysis were performed using the R statistical software (<http://www.R-project.org>). The effects of the pest management practices on the proportions of *B. tabaci* composition and the frequencies of resistance alleles were tested by using Fisher's exact tests.

## 3. Results

### 3.1 Geographic distribution of biotypes

All the 170 *B. tabaci* individuals collected in 5 localities in Burkina Faso, Benin and Togo belonged to MED-Q1 or ASL (Table 2). In Togo and Benin, only ASL was found (except one MED-Q1 individual in Tové), while in Burkina Faso, MED-Q1 and ASL were found in sympatry at variable frequencies: depending on the locality, it was either ASL or MED-Q1 that predominated. In Pô, the frequency of ASL reached more than 80% whatever the control strategy (CP or Cotton *Bt*). In Saria, MED-Q1 was more common than ASL, but their relative frequencies depended on the management program: on CP areas, 93 % of individuals belonged to MED-Q1 while only 57% of whiteflies were MED-Q1 on *Bt* Cotton fields (Fisher exact test,  $p < 0.005$ ).

### 3.2 Frequency of the L925I mutation

For the *para*-type voltage-gated sodium channel gene, we studied the frequency of the L925I mutation that correspond to the allele called r1 by Alon et al. (2008). We found high variations depending on the country (Fisher exact test,  $p < 0.0005$ ). Indeed, in Burkina Faso, r1



was fixed for both MED-Q1 and ASL in the two localities (Table 3). In Benin, this allele has not been found (Table 4). In Togo, its frequency varied between 0.5 and 0.75 (Table 5).

### 3.3 Frequency of the Ace- $I^R$ allele

For the acetylcholinesterase gene, we studied the presence of the F331W mutation (R allele). Globally, the frequency of this allele was more homogeneous among countries than for the L925I mutation and ranged between 0.71 and 1 (Fisher exact test,  $p=0.08$ ). In Togo, this frequency did not differ between the two localities, Infa and Tové (Table 5; Fisher exact test,  $p=0.1$ ). In Benin, where sampling was performed in only one locality, the frequency of R varied between 0.7 and 0.9 but did not significantly differ between the fields that were treated either with BP or CP program (Table 4; Fisher exact test,  $p=0.49$ ). In Burkina Faso, the frequency of the resistant allele changed in the two localities according to the treatment: it was lower in *Bt* Cotton areas than in CP fields (Table 3; Fisher exact test,  $p=0.003$  for Pô and  $p<0.0005$  for Saria). In the two localities, R was fixed in MED-Q1 in the CP fields while it had a frequency of 0.5 and 0.875 in Pô and Saria respectively in *Bt* areas (Fisher exact test,  $p<0.0005$ ). For ASL, differences were not so important and not statistically significant (Fisher exact test,  $p>0.05$ ) with a range of frequencies between 0.91 and 1 for CP fields and 0.71 - 0.83 for *Bt* cotton fields.

#### 4. Discussion

In this paper, we present the distribution of *B. tabaci* biotypes/species and the frequencies of the mutations in the para sodium channel gene (*kdr*) and in the Acetylcholinesterase gene (*ace-1<sup>R</sup>*) associated with resistance to Pyrethroids and Organophosphates respectively of the pest *B. tabaci* in 3 countries of Western Africa in connection with the pest management programs.

Our results confirmed the diversity of *B. tabaci* biotypes on cotton in these countries. As previously described by Gueguen et al. (2010) and Gnankiné et al. (2013b), MED-Q1 and ASL were detected in Burkina Faso, frequently in the same areas. Despite this sympatry, population genetics analyses on microsatellite markers suggested that MED-Q1 and ASL do not hybridize in the field (Mouton et al. 2015). It was also showed that they do not share insecticide resistance alleles. ASL previously classified in MED-species might thus be considered now as putative species (Mouton et al. 2015).

In the current study, the L925I mutation was fixed in MED-Q1 and ASL individuals in Burkina Faso. Regarding ASL, this is in sharp contrast with the situation observed in 2009 and 2010, as this mutation only reached 0.02 at that time in the western part of Burkina Faso (Mouton et al. 2015). This is also in contrast with the situation found in Benin, where this resistant allele was not found, whatever the control program. Finally, the situation is intermediate in Togo where the frequencies varied between 0.5-0.75 in CP or BP programs. The fixation of this L925I mutation might be explained by a high selection pressure due to the repetitive pyrethroids treatments applied in western Africa particularly on cotton and vegetables (Gnankiné et al., 2007; Ahouangninou et al., 2011; Gnankiné et al. 2013b).

The management of the resistance mutations in the *para*-type voltage-gated sodium channel gene, L925I but also T929V, seems to be difficult as they prove to be persistent even without

selection in laboratory, suggesting a low fitness cost (Roditakis et al., 2006). This low fitness cost was confirmed by Alon et al. (2006) where no departures from Hardy–Weinberg equilibrium were observed when the frequency of resistant genotypes was investigated in *B. tabaci* populations reared without any insecticide selection for many years. Accordingly, we could not detect any impact of the control program on the frequency of these resistance mutations.

For the F331W mutation (*ace1* gene), the frequencies of resistant alleles were very variable. According to Mouton et al. (2015), the frequencies of the F331W mutation in the *ace1* gene in individuals from Burkina Faso were 0.98 and 0.59 for MED-Q1 and ASL, respectively. Our data indicated that the frequency of resistance may be lower in individuals sampled in fields using *Bt* cotton strategy than in the fields using CP. This effect was more pronounced in MED-Q1 than ASL, and also more pronounced in Pô than in Saria. The high frequencies observed in Saria could be due to the number of applications done for the pest control. Indeed, near Saria, many farmers cultivate vegetables that are systematically treated with pyrethroids and Organophosphates. On the contrary, in Pô, no vegetables were cultivated and the insecticide pressure was low. Moreover, a drastic lack of resistant homozygous in the *Bt* cotton fields is consistent with the hypothesis of a high fitness cost associated with the F331W mutation in this species. As 90% of the zone was using *Bt* in Pô, while it was only 15% in Saria, the refuge zone without treatment is thus much more important in Pô, which could allow a more rapid counter-selection of resistance alleles without treatment. On the other hand, we could not detect any effect of the control program in Benin (CP vs. BP). This may be explained by the fact that only 10% of the surface were cultivated using BP program. In Togo, we did not detect any significant difference in the mutation frequencies in the two areas but they were under the same insecticide pressure.

Other mechanisms of insecticide resistance, like metabolic resistance may be associated to high frequencies of the two mutations in individuals insects conferring a multiple resistance. Indeed, detoxifying enzymes such as esterases, glutathione S-transferases, and cytochrome P450-dependent monooxygenases are involved in resistance to numerous insecticide classes (Alon et al., 2008; Rauch and Nauen, 2003; Ma W et al., 2010).

In conclusion, our results suggest that different control programs may alter the frequency of resistance alleles. However, the counter-selection of resistance alleles may depend on the one hand on the fitness cost associated with resistance, **and the other hand** to the relative surface of untreated areas. This clearly advocates for a better integration of control measures against *B. tabaci* across the different host crops.

## Acknowledgments

The authors are grateful to the following institute for the samples collection and the technical assistance from Inera and University of Lomé.

296

297

## 298 **References**

- 299 Ahouangninou C, F.B. and M.T., 2011. Évaluation des risques sanitaires et environnementaux  
300 des pratiques phytosanitaires des producteurs maraîchers dans la commune rurale de  
301 Tori-Bossito (Sud-Bénin). Cah. Agric. 20, 216–222.
- 302 Alon, M., Alon, F., Nauen, R., Morin, S., 2008. Organophosphates ' resistance in the B-  
303 biotype of *Bemisia tabaci* ( Hemiptera : Aleyrodidae ) is associated with a point mutation  
304 in an ace1 -type acetylcholinesterase and overexpression of carboxylesterase 38, 940–  
305 949. doi:10.1016/j.ibmb.2008.07.007
- 306 Alon, M., Benting, J., Lueke, B., Ponge, T., Alon, F., Morin, S., 2006. Multiple origins of  
307 pyrethroid resistance in sympatric biotypes of *Bemisia tabaci* (Hemiptera: Aleyrodidae).  
308 Insect Biochem. Mol. Biol. 36, 71–79. doi:10.1016/j.ibmb.2005.10.007
- 309 Gnankiné, O., Bassolé, I.H.N., Chandre, F., Glitho, I., Akogbeto, M., Dabiré, R.K., Martin,  
310 T., 2013a. Insecticide resistance in *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae)  
311 and *Anopheles gambiae* Giles (Diptera: Culicidae) could compromise the sustainability  
312 of malaria vector control strategies in West Africa. Acta Trop. 128.  
313 doi:10.1016/j.actatropica.2013.06.004
- 314 Gnankiné, O., Mouton, L., Henri, H., Terraz, G., Houndeté, T., Martin, T., Vavre, F., Fleury,  
315 F., 2013b. Distribution of *Bemisia tabaci* (Homoptera: Aleyrodidae) biotypes and their  
316 associated symbiotic bacteria on host plants in West Africa. Insect Conserv. Divers. 6.  
317 doi:10.1111/j.1752-4598.2012.00206.x
- 318 Gnankiné, O., Mouton, L., Savadogo, A., Martin, T., Sanon, A., Dabire, R.K., Vavre, F.,  
319 Fleury, F., 2013c. Biotype status and resistance to neonicotinoids and carbosulfan in  
320 *Bemisia tabaci* (Hemiptera: Aleyrodidae) in Burkina Faso, West Africa. Int. J. Pest  
321 Manag. 59. doi:10.1080/09670874.2013.771806

322 Gnankiné, O., Traoré, D., Sanon, A., Traoré, N.S. & Ouedraogo, A.P., 2007. Traitements  
323 insecticides et dynamique des populations de *Bemisia tabaci* Gennadius en culture  
324 cotonnière au Burkina Faso. Cah. Agric. 16.

325 Gueguen, G., Vavre, F., Gnankine, O., Peterschmitt, M., Charif, D., Chiel, E., Gottlieb, Y.,  
326 Ghanim, M., Zchori-Fein, E., Fleury, F., 2010. Endosymbiont metacommunities,  
327 mtDNA diversity and the evolution of the *Bemisia tabaci* (Hemiptera: Aleyrodidae)  
328 species complex. Mol. Ecol. 19, 4365–4376. doi:10.1111/j.1365-294X.2010.04775.x

329 Héma, O., Somé, H.N., Traoré, O., Greenplate, J., Abdennadher, M., 2009. Efficacy of  
330 transgenic cotton plant containing the Cry1Ac and Cry2Ab genes of *Bacillus*  
331 *thuringiensis* against *Helicoverpa armigera* and *Sylepte derogata* in cotton cultivation in  
332 Burkina Faso. Crop Prot. 28, 205–214. doi:10.1016/j.cropro.2008.09.014

333 Henri, H., Terraz, G., Gnankiné, O., Fleury, F., Mouton, L., 2013. Molecular characterization  
334 of genetic diversity within the Africa/Middle East/Asia Minor and Sub-Saharan African  
335 groups of the *Bemisia tabaci* species complex. Int. J. pest Manag. 59, 329–338.  
336 doi:10.1080/09670874.2013.869374

337 Houndeté, T. A., Kétoh, G.K., Hema, O.S. a, Brévault, T., Glitho, I. A., Martin, T., 2010.  
338 Insecticide resistance in field populations of *Bemisia tabaci* (Hemiptera: Aleyrodidae) in  
339 West Africa. Pest Manag. Sci. 66, 1181–1185. doi:10.1002/ps.2008

340 Ma W, Li X, Dennehy TJ, Lei C, Wang M, D.B. and N.R., 2010. Pyriproxyfen resistance of  
341 *Bemisia tabaci* (Homoptera: Aleyrodidae) biotype B: metabolic mechanism. J. Econ  
342 Entomol 103, 158–165.

343 Mike Mendelsohn, Kough1, J., Vaituzis, Z., Keith, M., 2003. Are Bt crops safe? Nat.  
344 Biotechnol. 21, 1003–1009. doi:10.1038/nbt0903-1003

345 Mouton, L., Gnankiné, O., Henri, H., Terraz, G., Ketoh, G., Martin, T., Fleury, F., Vavre, F.,  
346 2015. Detection of genetically isolated entities within the Mediterranean species of  
347 *Bemisia tabaci*: New insights into the systematics of this worldwide pest. Pest Manag.  
348 Sci. 71. doi:10.1002/ps.3834

- 349 Pardo-Lopez, L., Soberon, M., Bravo Alejandra, 2013. *Bacillus thuringiensis* insecticidal  
350 three-domain Cry toxins: mode of action, insect resistance and consequences for crop  
351 protection. *FEMS, Microbiol. Rev.* 37, 3–22. doi:10.1111/j.1574-6976.2012.00341.x
- 352 Rauch N and Nauen R, I. (2003)., 2003. Identification of biochemical markers linked to  
353 neonicotinoid cross resistance in *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Arch Insect*  
354 *Biochem Physiol* 54, 165–176.
- 355 Ruditakis, E., Tsagkarakou, A., Vontas, J., 2006. Identification of mutations in the para  
356 sodium channel of *Bemisia tabaci* from Crete, associated with resistance to pyrethroids.  
357 *Pestic. Biochem. Physiol.* 85, 161–166. doi:10.1016/j.pestbp.2005.11.007
- 358 Sanahuja, G., Banakar, R., Twyman, R.M., Capell, T., Christou, P., 2011. *Bacillus*  
359 *thuringiensis* : a century of research , development and commercial applications 283–  
360 300. doi:10.1111/j.1467-7652.2011.00595.x
- 361 Silvie, J.P., Renou, A., Vodounnon, S., Bonni, G., Obayomi, M., Héma, O., Prudent, P.,  
362 Sorèze, J., Ochou, G., Togola, M., 2013. Threshold-based interventions for cotton pest  
363 control in West Africa : What ’ s up 10 years later ? *Crop Prot.* 43, 157–165.
- 364 Tsagkarakou, A., Nikou, D., Ruditakis, E., Sharvit, M., Morin, S., Vontas, J., 2009. Molecular  
365 diagnostics for detecting pyrethroid and organophosphate resistance mutations in the Q  
366 biotype of the whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Pestic. Biochem.*  
367 *Physiol.* 94, 49–54. doi:10.1016/j.pestbp.2009.03.002
- 368 Vitale, J., Glick, H., Greenplate, J., 2006. The Economic Impacts of Monsanto’s Paper,  
369 Bollgard II in West Africa: Empirical Evidence from Burkina Faso, in: 10th ICABR  
370 Conference, Ravello, Italy.

371